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THE DESIGN ENGINEER'S CONCEPT OF THE RELATIONSHIP BETWEEN SYSTEM DESIGN CHARACTERISTICS AND TECHNICIAN SKILL LEVEL

David Meister, et al

Bunker-Ramo Corporation
Canoga Park, California

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AIR FORCE HUMAN RESOURCES LABORATORY
AIR FORCE SYSTEMS COMMAND
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FOREWORD

This study was initiated by the Training Research Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio, under Project 1710, "Human Factors in the Design of Training Systems," Task 1710-06, "Personnel, Training and Manning Factors in the Conception and Design of Aerospace Systems." The research was accomplished by the Human Factors Department, The Bunker-Ramo Corporation, Canoga Park, California, under Contract No. F33615-68-C-1367. Dr. David Meister was principal investigator, assisted by Mr. Dennis J. Sullivan and Mrs. Dorothy L. Finley. Dr. William B. Askren, HRTR, was the investigator for the Air Force Human Resources Laboratory. The research sponsored by this contract was started on 1 April 1968 and was completed on 31 March 1969. This report was submitted by the authors 30 June 1969.

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This technical report has been reviewed and is approved.

Gordon A. Eckstrand, PhD.
Chief, Training Research Division
Air Force Human Resources Laboratory

ABSTRACT

The purpose of the study described in this report was to investigate the design engineer's concept of the relationship between system characteristics and various skill dimensions. Fourteen paper and pencil tests specifically developed to examine these relationships were administered to eight design engineers during two four-hour sessions. Design characteristics significantly related to skill level are test points, internal components, checkout and troubleshooting procedures, type of test equipment required and go/no-go displays. Individual design concepts such as component repair, etc., are also significantly related to the amount of training required. The engineer's concept of skill level is more performance-oriented than that described by the Air Force Specialty Code designations. It was found that the engineer conceptualizes maintenance skill in terms of knowledge, troubleshooting ability and flexibility. A common denominator of skill parameters appears to be troubleshooting ability. Skill level appears not to be related in the engineer's mind to years of experience.

SUMMARY AND CONCLUSIONS

PROBLEM

Previous studies indicate that design engineers have great difficulty in understnading and utilizing Air Force descriptions of personnel skill. As a result, their designs often do not reflect adequate consideration of skill requirements. The present study sought to determine the understanding that design engineers have of personnel skill, and how they relate it to system design characteristics.

APPROACH

Fourteen paper and pencil tests specifically developed to examine these relationships were administered to eight design engineers during two four-hour sessions. A set of skill parameters and design characteristics was developed which hypothetically differentiated highly skilled maintenance personnel from those less skilled. Subjects were asked to categorize sample critical incidents illustrating these parameters and characteristics in two ways: as (1) engineers conceptualize skill differences; and (2) as engineers consider that skill would influence their hardware design.

RESULTS

The engineer relates a number of design concepts and characteristics such as test points, internal components, checkout and troubleshooting procedures, type of test equipment required to the skill level of the maintenance technician. Individual design concepts are also significantly related to the amount of training required. The engineer conceptualizes maintenance skill in terms of knowledge of the system, troubleshooting ability and flexibility, with the amount of troubleshooting ability emerging as the common denominator of the various skill levels studied. The engineer's concept of skill level is more performance oriented than that described by Air Force Specialty Code designations. Skill level appears not to be related in the engineer's mind to years of experience.

CONCLUSIONS

Design concepts and characteristics are related in the engineer's mind to different skill levels. Given a particular skill requirement, the engineer will include in his design those characteristics that he considers appropriate to that skill requirement. The engineer has a concept of skill level which is more operationally and performance oriented than described by the Air Force Specialty Code designations, with troubleshooting ability as

the generalized factor underlying all levels of skill. This suggests that, for the designer, skill level might meaningfully be defined as "degree of troubleshooting ability." Individual design concepts are significantly related in the engineer's mind to the amount of training required. A specification of the amount of training to be given to system personnel will therefore influence the type of design concept incorporated into new equipment.

OPERATIONAL IMPLICATIONS

Manpower requirements included in procurement documents should be phrased as explicit design requirements. The maximum number of personnel who will operate and maintain the system and the highest skill level of these personnel should be described. Skill level should be phrased in performance terms, and the design implications of manpower requirements should be explicitly stated as desired outputs of system design.

RESEARCH IMPLICATIONS

It is recommended that a "human resources data system development handbook" be developed which would describe the various classes of equipment and their design characteristics, together with the manning/skill dimensions required to operate and maintain that equipment, applicable training data, and characteristic task behaviors. Such a handbook could be constructed by (1) developing a taxonomy of design concepts and characteristics which differentiate various types of systems, (2) selecting operational systems in the Air Force which are representative of these classes, (3) going to the air bases at which these systems are to be found, and (4) performing an analysis of the task behaviors, skill parameters and design-skill relationships demanded by these systems. The handbook could then be provided to Air Force managers and design engineers so that, given a requirement to develop a system of a given type, they could retrieve the appropriate equipment design type and find the manning dimensions and design relationships required for the new design.

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SECTION I

INTRODUCTION

A. NATURE OF THE PROBLEM

Manpower in system development and operation can be described in terms of two basic dimensions: number and skill level. The human resources specialist seeks by means of various analyses and inputs to the system development process to optimize the number and skill level of personnel required to operate and maintain the system against such factors as available human resources, training costs, personnel maintenance costs, human contributions to system operations, etc. (Eckstrand, Askren, and Snyder, 1967; and Snyder and Askren, 1968).

To secure this desirable condition means that systems must be designed so that they can be operated and maintained by the desired personnel force. Although it would be desirable to accomplish this end simply by requiring that systems be designed in this way, it is impossible to do so without first describing to the engineer the relationship between personnel number and skill level and the design characteristics which the engineer incorporates in the new system.

That relationship operates in two ways: the imposition of a manpower requirement may force the design engineer to consider alternative design concepts; in the other direction, the manner in which he designs his system may require that certain numbers and types of personnel be supplied to operate and maintain that system. Thus one can look at the personnel design relationship in terms of the effect of personnel on design and the effects of design on personnel.

In the first case it is necessary to know in advance what the imposition of a manpower requirement will mean to design, in order to avoid constraining the engineer unreasonably. In the second case, in order to predict the number and type of manpower to support the new system, it is necessary to determine the implications of various types of design for the personnel who must be provided.

At the present time there exist no firm data concerning these personnel-design relationships. Because it is difficult to predict the effects of a manpower requirement on design, procurement agencies have been reluctant to specify concrete, stringent manpower requirements in system procurement documents. In consequence, since engineers tend to ignore generally worded requirements which lack concrete design implications, manpower requirements have in the past usually failed to have any meaningful effect on design.

A previous study by Meister, Sullivan and Askren, 1968, indicated that engineers have great difficulty in translating Air Force skill designations (e.g., 3, 5, 7-levels) into meaningful design terms. The concept of number of

personnel is relatively unambiguous, because it is uni-dimensional and quantitative. On the other hand, skill can be conceptualized in many dimensions, such as intelligence, aptitude, sensory capability. Three questions therefore arise:

(1) What dimensions are actually represented in the engineer's concept of skill? In order to impose skill requirements on engineers, it is necessary to describe these in terms of dimensions which are meaningful to the engineer.

(2) How are these dimensions described in performance terms?

(3) What are the implications of these skill dimensions for design (ie, what design characteristics are most appropriate for different levels of skilled personnel)?

The previous study by Meister et al., 1968 recommended further investigation into the skill problem. The study described in this report was an initial effort to specify the relationship between personnel characteristics (basically skill) and equipment design characteristics, as this relationship is viewed by the engineers who must translate personnel characteristics into design concepts.

B. PURPOSE OF THE STUDY

The overall purpose of the study was to investigate the relationship between skill dimensions and equipment design characteristics. Such a relationship, however, has many facets, each of which must be examined closely. For example, the nature of the engineer's reaction to a personnel skill requirement depends on how he conceptualizes that requirement; in other words, how he defines to himself what skill means. It is therefore necessary to determine what skill dimensions are considered by engineers to differentiate different levels of maintenance technician skills.

In order to explore how skill requirements affect design, it is necessary first to determine the different ways in which the engineer tends to design. This means that it is necessary to determine the <u>range</u> of design concepts which can be affected by the skill requirement.

The relationship between design and skill can be understood only in terms of how engineers view specific design characteristics and concepts to be related to the various skill dimensions and skill levels. Design too has many facets. What aspects of design are related to what aspects of skill? This too must be investigated.

Just as skill may have a number of different dimensions, so too it probably has a number of different levels. Obviously the nature of the

engineer's reaction to skill will be determined in part by the number of skill levels he can differentiate. If, for example, he considers skill to have only two levels (i.e., skilled-unskilled), the range of his design responses to a skill requirement will be correspondingly reduced.

Data describing skill are ordinarily presented to engineers in a variety of interactive ways. in the form of specific requirements (e.g., "design so that equipment can be operated and maintained by 3-level personnel"); in the form of personnel descriptions (*e.g.*, Quantitative and Qualitative Personnel Requirements Information); in the form of analyses such as task descriptions and time-line analyses; in the form of availability statements (e.g., "highly trained personnel from the X system will be made available to operate and maintain the new system"); in terms of anticipated training time and costs. It is therefore necessary to determine which of these types of skill descriptions are most readily utilized by engineers and in particular at what stage of system development they are most useful.

Since skill is not the only design parameter considered by engineers in making design decisions, it is important to determine the weighting they assign to skill in relation to other parameters.

Skill is ordinarily viewed by behavioral scientists as related in some way to the amount of experience that personnel have had in the same or related technical specialty. It is therefore essential to determine whether the engineer equates various levels of skill with different amounts of experience.

If a relationship exists between personnel and design characteristics, it seems reasonable to assume that various design characteristics will have different implications for the amount of training needed by personnel to achieve proficiency in maintaining equipment with these design characteristics.

The present study can therefore be more effectively described by a series of questions which the study sought to answer. These are summarized as follows:

(1) What design characteristics and design concepts are considered by engineers to be related to skill dimensions and skill levels?

(2) How many independent design concepts can be differentiated by engineers?

(3) What priority do engineers apply to design parameters (including skill and other human resources data) in making design tradeoffs?

(4) How are design concepts related in the engineer's opinion to amount of training required by these design concepts?

(5) What skill dimensions are considered by engineers to differentiate different levels of maintenance technician skill?

(6) How many levels of skill can be differentiated by engineers?

(7) What is the relationship in the engineer's mind between skill level and years of experience?

The ultimate purpose of the present study, which was that also of the previous one, is to derive from the controlled testing of engineers certain personnel-design relationships which would enable the Air Force to write more effective procurement requirements. It is assumed that if, instead of general, non-enforceable manpower provisions, explicit design-relevant statements of personnel needs can be incorporated in procurement requirements, more satisfactory systems will be developed.

SECTION II

TEST METHODOLOGY

A. GENERAL STRATEGY

The overall research strategy involved selecting a group of highly experienced design engineers and presenting them with a series of specially developed tests which examined each of the questions described in the previous section.

As part of another study, reported in Meister, Sullivan, Finley, and Askren, 1969, these subjects had been required, immediately prior to entering the test situation described in this report, to perform the conceptual (paper) design of a missile subsystem. Since the inputs provided in this design simulation included the equipment and HRD inputs normally provided in system development, and since they were required to make highly explicit design decisions, subjects were familiar with the types of personnel inputs and design problems they were asked to examine in the present test series. Since the earlier HRD inputs were specific to the design problem presented in the previous study, whereas the test inputs for the present study were generalized to all design, subjects were not influenced in any particular response direction by the earlier inputs.

It appeared feasible to apply a job analysis technique to the investigation. A set of skill parameters and design characteristics - as large as one could reasonably conceptualize - was developed which hypothetically differentiated highly skilled maintenance personnel from those less skilled (e.g., apprentices). Sample critical incidents illustrating these parameters were developed. Design engineers were asked to categorize these incidents and parameters in two ways: as (1) they conceptualized skill differences and (2) as they considered that skill would influence their hardware design.

All of the test items were administered as paper and pencil tests and given to subjects individually in two four-hour sessions. The items within a given session were presented in a random order to compensate for serial and fatigue effects. Although these were formal tests, they were also used as a springboard for detailed discussions between the investigators and the subjects. The general procedure was to administer the individual test and then follow it up by a discussion with the subject concerning the nature and reason for his responses, before going on to the next test. This permitted more meaningful interpretation of the subjects' responses.

B. SUBJECTS

The eight engineers who made up the subject population for this study were selected from the test engineering department of the Marquardt Corporation, Van Nuys, California. Engineers were selected from this company because the previous study (Meister et al, 1969) had required the selection of personnel skilled in the design of test equipment used to check out missiles and missile-related equipment.

An analysis of the education and experience background of the subjects is presented in Table I. The average amount of experience is 15.7 years, with no subject having less than 8. It can be said therefore that all subjects were highly experienced. Moreover, they are essentially equivalent in terms of relevant experience to those of an earlier study (Meister et al., 1968), in which the mean experience level was 17.3 years.

C. TEST DESCRIPTION

The following tests were developed to examine each of the study questions asked in Section I. Tests are listed in Table II and described in terms of each of the questions they sought to investigate. The tests themselves and the instructions given subjects are presented as part of the Results section (III).

1. <u>What design characteristics and design concepts are considered by engineers to be related to skill dimensions and skill levels?</u>

In order to structure this question the investigators differentiated between design characteristics and design concepts in the following way. Design characteristics are relatively detailed aspects of design, such as the size of access spaces, or the placement of related controls and displays. Design concepts are <u>combinations</u> of design characteristics which describe the way in which individual equipment characteristics interrelate. For example, modular packaging (a design concept) might include access space, test point location and arrangement, and level of required troubleshooting (each of which is a design characteristic). Engineers design equipment in terms of design concepts, such as level of automation, and the design characteristics relevant to those concepts fall out of the concepts; however, maintenance men respond directly to the individual design characteristics.

Skill dimensions are different ways in which an individual's skill (at any level) can be manifested, e.g., in response speed, or accuracy. Skill levels represent varying amounts of skill.

In Test C (Skill vs. Design Characteristics Test) subjects indicated whether the inclusion of various types of characteristics could be affected by the requirement to use an unskilled man as operator or maintainer.

TABLE I

SUBJECT EDUCATION AND EXPERIENCE

Subject	Education	Years of Experience
Y	BSEE	12
L	BSEE	11
F	BS	17
Mc	MSEE	12
M_o	BSEE	8
M_a	BSEE	21
K	BSEE	22
W	BS	23
		15.7

TABLE II

LIST OF TESTS ADMINISTERED TO SUBJECTS

Test	Title	Relevant Study Question
A	Skill Dimensions	1
B	Skill Importance	1
C	Skill vs. Design Characteristics	3
D	Design Tradeoff Priorities	6
E-1	Skill vs. Experience Level	7
E-2	Skill vs. Automation	3
E-3	Skill vs. Design Concepts	3
F	Design Independence	2
G	Design Suitability	3
H	Skill Ranking	1
I	Design vs. Training	8
J	Skill Level Differences	4

In Test E-2 (Skill vs. Automation Test) subjects were asked to indicate how they viewed the relationship between level of automation and skill level.

In Test E-3 (Skill vs. Design Concepts Test) and Test G (Design Suitability Test) subjects indicated whether a limited number of basic design concepts (as differentiated from the molecular equipment characteristics of test C) were related more to skilled than to unskilled personnel.

2. How many independent design concepts can be differentiated by engineers?

In order to relate design characteristics to skill levels, it is necessary first to establish what the engineer considers to be independent (i.e., homogeneous, non-interactive) design concepts. In test F (Design Independence Test) subjects were given fourteen design concepts and asked to determine which of these are related or independent.

3. What priority do engineers assign to design parameters (including HRD inputs) in making design tradeoffs?

This question had been asked in previous studies (Meister and Sullivan, 1967, and Meister et al., 1968). It was considered desirable to determine whether the present subjects utilized the same design tradeoff orientation. In Test D (Design Tradeoff Priorities Test) subjects were asked to rank twelve design parameters in terms of importance to design decisions.

4. What skill dimensions are considered by engineers to differentiate different levels of maintenance technician skill?

Test A (Skill Dimensions Test) presented a series of statements describing how maintenance technicians perform. Each statement was an incident descriptive of a skill dimension. Subjects were asked to categorize each statement as characteristic of a skilled or unskilled man. Those statements on which significant agreement among subjects could be reached would presumably describe the effective parameters of maintenance skill as defined by the designer. The following tests, dealing with the same question, were also presented:

In Test B (Skill Importance Test) subjects indicated the contribution of each of nineteen skill dimensions to maintenance skill on a 5 point scale.

In Test H (Skill Ranking Test) subjects were asked to rank the nineteen skill dimensions of Test B in terms of their importance to overall skill.

5. How many levels of skill can be differentiated by engineers?

The Air Force generally utilizes a three-step skill level continuum (3, 5, 7-level) which lacks correlated performance descriptors. It was considered possible that a finer skill level continuum, phrased in terms of characteristic maintenance performance, could be utilized more readily

by engineers. The purpose of Test J (Skill Level Differences Test) was to determine whether subject agreement could be reached on the steps within that expanded skill continuum. Subjects were given a 10 point scale of skill level and asked to assign each point to a continuum ranging from completely unskilled to completely skilled.

6. What is the relationship in the engineer's mind between skill level and years of experience?

Skill level and experience would seem to be somehow related. It was considered possible that some quantitative relationship might be established between these two variables. In Test E-1 (Skill vs. Experience Level Test) subjects were asked to assign four levels of skill to a time scale ranging from zero years experience to 10 years experience.

7. How are design concepts related in the engineer's opinion to the amount of training required by these design concepts?

A relationship between design concepts and amount of training has commonly been assumed in most manpower planning, but the nature of the relationship has not been investigated, at least quantitatively. This question was an attempt to scale design concepts in terms of amount of required training.

In Test I (Design vs. Training Test) the design concepts studies in Test F (Design Independence Test) were given to subjects with instructions to rank each concept in terms of the amount of training that concept would appear to require.

SECTION III

RESULTS AND CONCLUSIONS

A. SUMMARY

The following conclusions were derived from this study.

1. Engineers consider (at the .001 level of agreement) that the following design characteristics are most appropriate for skilled personnel: quantitative displays; special purpose test equipment; troubleshooting down to the circuit level; component repair required; on-site maintenance and calibration.

2. Engineers consider (at the .001 level of agreement) that the following design characteristics are most appropriate for unskilled personnel: go/no-go displays, step by step procedures; throw away maintenance concept; and subsystem as opposed to component checks.

3. The following design attributes are considered to be essentially independent (i.e., unrelated to other design approaches); unit packaging; individual packaging; circuit level troubleshooting; redundancy; manual control; and scale type information. Apparently the general design concept of automatic vs. manual equipment can be broken down into the above parameters.

4. The following design concepts are significantly related (in the engineers' mind) to skilled personnel: manual control; multi-purpose equipment; circuit level troubleshooting.

5. The amount of training required for operation/maintenance of equipment varies as a function of design attributes, ranging from those requiring most training: circuit level troubleshooting, multi-purpose equipment and scale type displays, to those requiring least training: self-check capability; special purpose equipment; and go/no-go information.

6. Engineers have a much more precise concept of what constitutes skilled maintenance behavior than they have of unskilled behavior, based on the consistency of their responses to skilled vs. unskilled characteristics.

7. All eight subjects agreed that the parameters which they conceive of as differentiating skilled from unskilled maintenance personnel are:

Characteristics of Skilled Personnel	Characteristics of Unskilled Personnel
Knowledge	Accuracy (lack of)

Characteristics of Skilled Personnel	Characteristics of Unskilled Personnel
Problem-solving (troubleshooting ability)	Knowledge (lack of)
Flexibility	Problem solving (lack of ability to troubleshoot)

8. The following parameters, in decreasing order of importance, are considered to contribute most to skilled performance: integration of information, knowledge, accuracy, problem solving, training, use of instruments, flexibility, stress performance, visual capacity and responsibility.

9. When subjects were asked to rank order the nineteen skill parameters in terms of relative importance, seven of the ten parameters noted in (8) above were included, the only exceptions being: use of instruments; stress performance; and visual capacity.

10. Engineers consider that skill is less important for determining design characteristics than equipment performance capability, equipment reliability, cost, maintainability and producibility.

11. There is no consistency in engineers' estimates of the amount of time required for an individual to achieve various skill levels. No significance is attached by the design engineer to time on the job as an isolated descriptor of skill.

12. Engineers claim to be capable of differentiating (at the .001 level of significance) ten levels of personnel skill.

B. DETAILED RESULTS

The following questions were answered in the skill investigation study. Following a statement of the question a description (with subject instructions) of each test is given, followed by a statistical analysis of the results and the conclusions derived from the results.

1. What design characteristics and design concepts are considered by engineers to be related to skilled dimensions and skill levels?

Tests C, E-2, E-3, and G are directed toward answering this question.

TEST C

SKILL VS. DESIGN CHARACTERISTICS TEST

Test Description and Instructions

In this test we wished to determine how the engineer relates the skill characteristics of the personnel who are going to operate and maintain his equipment to the characteristics of that equipment.

Subjects were presented with two lists of characteristics: one describing the personnel who would be responsible for operation and maintenance of the system and the second describing the characteristics of that equipment. Originally it was planned to have the subjects consider each personnel characteristic (based on the nineteen parameters, which would have made nineteen characteristics) individually against each equipment characteristic. However, the number of comparisons required quickly exhausted the subjects and it became necessary to collapse the individual personnel characteristics into three which described (1) a relatively low skilled, (2) not too intelligent, (3) inexperienced individual. Subjects then judged whether or not a particular design characteristic would be affected by the requirement to use this type of man as operator or maintainer.

"One of the things we want to find out is how the engineer relates the skill characteristics of the people who are going to operate and maintain equipment to the characteristics of the equipment he is designing. This assumes, of course, that he designs his equipment to fit as much as possible the characteristics of its users.

"Imagine then that you are designing the electronic subsystem of a missile or a maintenance ground equipment and that you have a description of the people who will have to use and maintain the equipment. These individuals can be summed up in three phrases: (1) relatively low skilled; (2) not too intelligent; (3) inexperienced. These characteristics are constraints on your design, because you are designing for relatively unskilled personnel. We want you to match these personnel characteristics to the characteristics of the equipment you are designing, for example, the weight or the dimensions of the equipment.

"We will function something like this. I want you to go through the list of design characteristics on your answer sheet. As you do so, ask yourself whether you could somehow modify the design of that equipment characteristic to make it easier for this unskilled technician to do his job better.

"Just as an example, one of the equipment characteristics listed is "type of displays - quantitative or go/no-go". You might feel that if the technician is relatively unskilled he might not be able to assimilate any more information than that provided in go/no-go displays; so you would design your equipment to have go/no-go displays. You want to ask yourself the same question for each of the design characteristics listed on your answer sheet. That sheet contains three answers you can give to the question: no effect; slight effect; major effect. If there is no possible way in which the design characteristic could be modified to fit these personnel characteristics, you would check the box labeled "no effect". If the design characteristic could be modified, but only slightly, you would check the box labeled, "slight effect". If the design characteristic could be affected significantly by the skill characteristic, you would check the box labeled, "major effect". Is that clear?

"Now study the list of equipment characteristics. If you have any questions at any time about what you are supposed to do or what each of these characteristics means, let me know. You may wish to comment on your answer; please do so. Take as much time as you feel you need."

Conclusions and Interpretations

To analyze the results of test C the X^2 one-sample test (Siegel, 1956) was used. In effect this statistical test indicates the amount of agreement among subjects in relating skill as a design constraint to particular design characteristics.

An examination of Table III(a), which presents the frequencies of subject choices, together with interpretative comments, reveals that the following design characteristics are significantly related to lack of skill: arrangement of internal components, type of test equipment required, type of information displays, type of troubleshooting symptoms and step by step procedures.

If the two categories (slight effect; major effect) are collapsed into a single category (some or major effect), (Table III(b)), the relationship between design characteristics and skill becomes much stronger.

Table III(b) indicates the following:

Design Characteristics Significantly (.05 Level) Related To Low Skill Level	Design Characteristics Significantly (.05 Level) Unrelated To Low Skill Level
Test points	Weight
Internal Components (a) arrangement (b) accessibility	Dimensions Type of equipment connectors
Checkout procedures (a) type (b) length (c) availability of feedback (d) number of personnel required	Drawings/schematics Access space Standardization of fasteners
Type of test equipment required	
Go/no-go displays	
Troubleshooting procedures (a) symptoms (b) feedback indications (c) level of troubleshooting required	
Step by step procedures	

Those design characteristics not listed above are ambiguous in their relationship to skill level; in other words, engineers are divided in their opinion as to the relationship.

It must be emphasized that these are relationships as the engineer sees them. These are the relationships on which the engineer will act in his design. Since they are judgmental only, they should not be accepted as demonstrating the existence of an actual, empirically derived relationship.

The implications of these findings is that should the developer be required to design for low level personnel, he is more likely to include in his equipment the design characteristics which he has noted as being related to unskilled performance. In addition, there would seem to be a definite relationship between certain classes of design characteristics and the skill levels of the personnel expected to be operating that equipment; further research in this area would seem to be necessary in order to examine the relationship of major categories of equipment characteristics and skill levels.

TABLE III(A)

RESULTS OF TEST C
(SKILL VS. DESIGN CHARACTERISTICS)

WITH ORIGINAL CATEGORIES

Item	No Effect	Slight Effect	Major Effect	Responses
1. Weight	8			Subjects were unanimous in agreeing that equipment, weight, and dimensions are not related to skill.
2. Dimensions	8			
3. Test Points				
a. Number	2	2	4	Subjects were divided on this question, with approximately half of them indicating a strong relationship between test point characteristics and skill.
b. Location	2	2	4	
c. Identification	2	1	5	
d. Arrangement	2	1	5	
4. Internal Components				
a. Type	4		4	Here again we have an almost equal split as to the relationship of personnel characteristics to the layout and selection of internal components.
b. Number	3	2	3	
c. Arrangement	1	2	5	
d. Accessibility	2	2	4	
5. Checkout Procedures				
a. Type	2	1	5	The nature of checkout procedures is seen as being very much a function of personnel skill and experience.
b. Length	2	2	4	
c. Frequency of Performance	5	1	2	
d. Availability of Feedback	2		6	
e. Number of Personnel Required	2	1	5	

TABLE III(A)

RESULTS OF TEST C
(SKILL VS. DESIGN CHARACTERISTICS)

WITH ORIGINAL CATEGORIES

Item	No Effect	Slight Effect	Major Effect	Responses
6. Equipment Connections Required				
a. Number	4	3	1	Subjects saw very little relationship between personnel characteristics and connector selection and utilization.
b. Type	7	1		
7. Test Equipment/Tools Required				
a. Type				Subjects perceive test and checkout philosophy and implementation as being directly related to the characteristics of the personnel who will use the equipment. The number of test eqnipments required does not seem to be so related.
1. Manual/Automatic		3	5	
2. Portable/Built-in	1	4	3	
3. General Purpose/Special		3	5	
b. Number	4	2	2	
8. Test Information Displays				
a. Number	3	1	4	Subjects seem split as to whether skill level is related to number of displays. There seems to be no doubt, however, that the type of display provided is definitely a function of personnel characteristics.
b. Type				
1. Quantitative/Qualitative	3		5	
2. Go/No-Go	1		7	
9. Troubleshooting Procedures				
a. Symptoms				The nature of troubleshooting procedures, the level to which they are carried, and the kind of feedback required, are
1. Quantitative/Qualitative	1		7	

TABLE III(A)

RESULTS OF TEST C
(SKILL VS. DESIGN CHARACTERISTICS)

WITH ORIGINAL CATEGORIES

Item	No Effect	Slight Effect	Major Effect	Responses
2. Single/Multiple	4		4	significantly related to personnel characteristics, with number of personnel required and the nature of symptom presentation being somewhat less closely related.
b. Number of Steps	3	1	4	
c. Feedback Indications	2	1	5	
d. Number of Personnel Required	3	1	4	
e. Level of Trouble-shooting Required	2		6	
10. Type of Instructions				
a. Step-by-Step Procedures	1		7	Subjects report that step-by-step procedures are required for unskilled personnel. However, drawings, schematics, and signal flow diagrams apparently cannot be tied to a particular skill level.
b. Signal Flow Diagrams	4	2	2	
c. Drawings, Schematics	7	1		
11. Access				
a. Spaces				The number and size of access spaces and their covers are definitely not related to a given skill level. What is important is simply that there be access.
1. Number	6		2	
2. Size	6		2	
b. Covers	6		2	
12. Coding/Labeling	5	1	2	Unrelated to skill level.
13. Standardization				
a. Components	4	1	3	Standardization of components and fasteners appears not to be related to skill level.
b. Fasteners	8			

TABLE III(A)

RESULTS OF TEST C
(SKILL VS. DESIGN CHARACTERISTICS)

WITH ORIGINAL CATEGORIES

Item	No Effect	Slight Effect	Major Effect	Responses
14. Safety	4	3	1	"Safety is a primary consideration at all times", regardless of personnel characteristics. Some of the subjects, however, would hedge this a bit by paying a little more attention to safety for unskilled personnel.

TABLE III (B)

RESULTS OF TEST C
(SKILL VS. DESIGN CHARACTERISTICS)

WITH COLLAPSED CATEGORIES

Item	No Effect	Some or Major Effect	X^2	P
1. Weight	8		16.0	.001
2. Dimensions	8		16.0	.001
3. Test Points				
a. Number	2	6	7.0	.05
b. Location	2	6	7.0	.05
c. Identification	2	6	7.0	.05
d. Arrangement	2	6	7.0	.05
4. Internal Components				
a. Type	4	4	4.0	NS
b. Number	3	5	4.75	NS
c. Arrangement	1	7	10.75	.01
d. Accessibility	2	6	7.0	.05
5. Checkout Procedures				
a. Type	2	6	7.0	.05
b. Length	2	6	7.0	.05
c. Frequency of Performance	5	3	4.75	NS
d. Availability of Feedback	2	6	7.0	.05
e. Number of Personnel Required	2	6	7.0	.05
6. Equipment Connections Required				
a. Number	4	4	4.0	NS
b. Type	7	1	10.75	.01
7. Test Equipment/Tools Required				
a. Type				
1. Manual/Automatic		8	16.0	.001
2. Portable/Built-In	1	7	10.75	.01
3. General Purpose/Special		8	16.0	.001

TABLE III(B)

RESULTS OF TEST C
(SKILL VS. DESIGN CHARACTERISTICS)

WITH COLLAPSED CATEGORIES

Item	No Effect	Some or Major Effect	X^2	P
b. Number	4	4	4.0	NS
8. Test Information Displays				
a. Number	3	5	4.75	NS
b. Type				
1. Quantitative/ Qualitative	3	5	4.75	NS
2. Go/No-Go	1	7	10.75	.01
9. Troubleshooting Procedures				
a. Symptoms				
1. Quantitative/ Qualitative	1	7	10.75	.01
2. Single/Multiple	4	4	4.0	NS
b. Number of Steps	3	5	4.75	NS
c. Feedback Indications	2	6	7.0	.05
d. Number of Personnel Required	3	5	4.75	NS
e. Level of Trouble-shooting Required	2	6	7.0	.05
10. Type of Instructions				
a. Step-by-Step Procedures	1	7	10.75	.01
b. Signal Flow Diagrams	4	4	4.0	NS
c. Drawings, Schematics	7	1	10.75	.01
11. Access				
a. Spaces				
1. Number	6	2	7.0	.05
2. Size	6	2	7.0	.05
b. Covers	6	2	7.0	.05
12. Coding/Labeling	5	3	4.75	NS

TABLE III(B)

RESULTS OF TEST C
(SKILL VS. DESIGN CHARACTERISTICS)

WITH COLLAPSED CATEGORIES

Item	No Effect	Some or Major Effect	X^2	P
13. Standardization				
a. Components	4	4	4.0	NS
b. Fasteners	8		16.0	.001
14. Safety	4	4	4.0	NS

TEST E-2

SKILL VS. AUTOMATION TEST

Test Description and Instructions

In this test subjects were presented with five true/false questions regarding the relationship between level of automation and personnel skill level. The questions are presented in Table IV.

Conclusions and Interpretations

The Binomial test (Siegel, 1956) was applied to determine whether the distribution of true/false responses varied significantly from what one might expect by chance. Four of the five items are highly significant.

It would seem from Table IV that design engineers have a pronounced bias toward designing the operator out of their equipment, regardless of personnel requirements levied in a particular situation. Even item C in the table, which practically "leads" the respondent into a response favoring a manual design, fails to meet significance standards, although five of the subjects did agree with the statement.

Test responses are, moreover, corroborated by subjects' behavior on the major design problem performed in the earlier sessions. The same behavior has been observed also in engineers used as subjects in previous studies (Meister et al, 1968).

TEST E-3

SKILL VS. DESIGN CONCEPTS TEST

Test Description and Instructions

"Indicate whether the following equipment characteristics would be appropriate for or could be used more readily by skilled or unskilled personnel. Put S opposite the item if it is more appropriate for skilled personnel; U opposite the item for unskilled or relatively unskilled personnel. Place a question mark opposite the item if it is applicable to both skill levels or neither."

Conclusions and Interpretations

Twenty-eight equipment characteristics were presented, of which twenty-two reached a X^2 significance level of agreement of .05 or better. The equipment characteristics applicable to unskilled personnel are listed in Table V(a); those applicable to skilled personnel are shown in Table V(b). The six characteristics which were insignificantly

TABLE IV

RESULTS OF TEST E-2

(SKILL VS. AUTOMATION TEST)

		T	F	P
A.	All other things being equal, when system requirements are quite stringent (e.g., high reliability, short turn around time), I prefer to make my equipment more automatic than manual.	8		.004
B.	All other things being equal, if an equipment requires major analyses or decisions to be made, I prefer to automate these decisions, unless I can be sure of having highly skilled personnel to operate and maintain the equipment.	7	1	.035
C.	Certain types of systems (such as those which require sensing or interpreting data) seem to me to require more manual design than others.	5	3	.145 NS
D.	Regardless of the skill of the personnel who will operate and maintain the equipment, I am designing, I prefer to minimize the possibility of error by designing the equipment to be as automatic as possible (all other things, like cost, being equal).	8		.004
E.	When I am told that the personnel who will operate and maintain the equipment will be low level technicians, I tend to make my equipment more manual (all other things, like cost, being equal).		8	.004

TABLE V (A)

RESULTS OF TEST E-3
(SKILL VS. DESIGN CONCEPTS)

FOR UNSKILLED PERSONNEL

Design Concepts	X^2	P	Distribution of Responses: Skilled	Unskilled	?
Built-in Test Equipment	10.75	.01	1	7	
All Similar Components in One Module	10.75	.01		7	1
Go/No-Go Displays	16.0	.001		8	
Relatively Short Checkout Procedures	10.75	.01	1	7	
Internal Components Arranged by Signal Flow	7.0	.05		6	2
All Similar Components Grouped in One Module	7.0	.05		6	2
Step by Step Procedure	16.0	.001		8	
Fixed Maintenance Equipment	7.0	.05		6	2
Throw Away Maintenance Concept	16.0	.001		8	
Subsystem Checks which indicate that the Subsystem is either Go/No-Go	16.0	.001		8	

TABLE V (B)

RESULTS OF TEST E-3
(SKILL VS. DESIGN CONCEPTS)

FOR SKILLED PERSONNEL

Design Concepts	X^2	P	Distribution of Responses Skilled	Unskilled	?
Quantitative Displays	16.0	.001	8		
Portable Test Equipment	7.0	.05	6		2
As Much Feedback Information Displayed as Possible	10.75	.01	7		1
Special Purpose Test Equipment	16.0	.001	8		
As Many Test Points as Possible	7.0	.05	6	2	
Scope Pattern Interpretation Required	10.75	.01	7	1	
Troubleshooting down to the Circuit Level	16.0	.001	8		
Component Repair Required	16.0	.001	8		
On-Site Maintenance	16.0	.001	8		
Visual Inspection of Components Required	6.25	.05	6	1	1
Limited Number of Maintenance Personnel	10.75	.01	7	1	
Calibration Required	16.0	.001	8		

related to either skilled or unskilled personnel are: test points as close as possible to the components they checkout; internal components stacked; test points located in a single module; long checkout procedures broken up by summary status checks; mobile maintenance equipment; signal flow diagrams and schematics.

Test E-3 is related to Test C (Skill vs. Design Characteristics) and supplies somewhat similar answers. Just as in Test C, engineers are likely (all other things being equal) to provide skilled personnel with quantitative displays, as much feedback information and test points as possible, to require troubleshooting (component repair and on-site maintenance also imply troubleshooting) and calibration, etc. Designing for unskilled personnel implies built-in test equipment, go/no-go displays, short checkout procedures, step by step procedures, throw-away maintenance (thus avoiding the need to troubleshoot), etc.

Again, the chances are that requiring that equipment be designed to either high or low skilled personnel will predispose the engineer to design with the appropriate related characteristics. This is not necessarily bad, since there is a logic behind the relationship of skill and design characteristics. However, it is necessary to know what the relationship is to be able to control more efficiently the engineer's design tendencies.

TEST G

DESIGN SUITABILITY TEST

Test Description and Instructions

"In Test F we gave you a set of design concept descriptions. Now we would like to find out which of these design concepts are more suitable for skilled than for unskilled personnel, and vice versa. If the concept has no relation to skill level, place a check in the "no difference" column. Read the definitions in Test F over again and place a check in the appropriate column below."

Conclusions and Interpretations

Table VI presents the distribution of judgments across the three categories. If the null hypothesis is correct (that there is no difference among the frequencies of choice among skilled, unskilled and no difference), one would expect a frequency of 8/3 in each column. This permits the use of X^2 as a measure of significance between expected and actual values. Table X indicates that 4 of the 14 cases are consistently identified as having some relationship to skill (at the .05 level or better). These are:

(1) Manual control (skilled)

(2) Multi-purpose equipment (skilled)

(3) Circuit level troubleshooting (skilled)

(4) Scale type information (skilled)

It was indicated in the interpretation of Test A (Skill Dimensions) that engineers have a more precise concept of skilled than unskilled behavior. This is markedly demonstrated again in Test G, where all significant relationships refer to skilled behavior.

It may be of some significance that three of the design concepts related to skill are among the "independent" concepts of Test F (Design Independence).

Discussion of Conclusions Relative to Question 1

It is apparent from the preceding four tests that engineers (consciously or not) relate individual design concepts and characteristics to skilled and unskilled behaviors. Given a particular skill requirement the engineer is more likely than not to include in his design, characteristics which he considers appropriate to that skill requirement. Table V(a) and V(b) list the characteristics he considers appropriate to particular skill levels. Given no skill requirement, he is more likely than not, all other things being equal, to automate his design.

These results suggest even more strongly the need to include specific skill requirements in procurement specifications. The absence of any requirement leaves him free choice to indulge his biases; and, as certain of the subjects of this study indicated, he tends very strongly to design in accordance with these biases. It would seem desirable to control the engineer's design propensities as much as possible (however much this may be) by imposing as many pertinent requirements on him as is feasible.

TABLE VI

RESULTS OF TEST G
(DESIGN SUITABILITY TEST)

Design Concepts	Distribution of Responses: Skilled	Unskilled	No Difference	X^2	P
Complete Automation	1	5	2	3.25	NS
Semi-Automation	4	2	2	1.0	NS
Manual Control	7	1		10.75	.01
Self-Check Capability	1	5	2	3.25	NS
Multi-Purpose Equipment	7		1	10.75	.01
Special Purpose Equipment	2	3	3	.25	NS
Modularized Equipment	2	4	2	1.0	NS
Unit Packaging	5		3	4.75	NS
Individual Packaging	5	2	1	3.25	NS
Circuit Level Troubleshooting	8			16.0	.001
Module Troubleshooting	3	3	2	.25	NS
Go/No-Go Information	1	5	2	3.25	NS
Scale Type Information	7	1		6.25	.05
Redundancy	4	1	3	1.75	NS

2. How many independent design concepts can be differentiated by engineers?

Test F (Design Independence Test) was directed at answering this question.

TEST F

DESIGN INDEPENDENCE TEST

Test Description and Instructions

"In this series we want to explore different types of design concepts. Please study the descriptions of equipment characteristics below. Imagine that you would have to design to these requirements. Then turn to the accompanying matrix table. You will see the design concepts described by these characteristics listed on the left and top side of the matrix table. Put a check mark in each cell of the table where the design approach for the various concepts is the same. For example, if the design approach for modularized equipment is the same as that for an equipment with self check capability, you would put a check in the cell where these two descriptions intersect. If the design requirements for different equipment characteristics are different, leave the cell blank."

Complete Automation

All functions are performed automatically by the equipment. The operator merely monitors its performance.

Semi-Automation

The equipment performs functions up to a certain stage, then waits until the operator decides to go to the next functional stage of operation.

Manual Control

The equipment performs no functions without the operator first initiating a control action.

Self-Check Capability

The system has the capability to check its own functioning and to localize its faults down to a given level.

Multi-purpose Equipment

The equipment is highly flexible and performs several functions.

Special Purpose Equipment

The equipment is specially designed for a particular purpose and performs only a single function.

Modularized Equipment

The internal components of the equipment are packaged in a modular fashion.

Unit Packaging

The equipment has individual assemblies to perform several different functions; however, they are all packaged in the same unit.

Individual Packaging

The equipment is broken up into a number of individual units which can be hooked together in different arrangements to checkout different assemblies.

Circuit Level Troubleshooting

Troubleshooting of this equipment is required down to the circuit level.

Module Troubleshooting

Troubleshooting of this equipment is required only down to the module level.

Go/No-Go Information

This equipment provides information to the technician in go/no-go form.

Scale Type Displays

This equipment provides information to the technician in the form of quantitative, scale type displays.

Redundancy

This equipment has at least one redundant unit or path for each major function performed.

Statistical Analysis

The subjects made one of two possible responses for each matrix cell, with the unbiased probability of indicating that any two design concepts are equivalent being .5. Therefore, the Binomial Test (Siegel, 1956) is applicable and the specific probabilities for selection of two design concepts as being equivalent are as follows:

Cell Frequency

Equivalent Yes		Not Equivalent No	Specific Probability	Frequency of Occurrence
8	+	0	P = .004	15
7	+	1	P = .035	16
6	+	2	P = .145 Not sig.	24
5	+	3	P = .363 Not sig.	25
4	+	4	P = .637 Not sig.	11
			TOTAL MATRIX CELLS	9[illegible]

To develop a measure of the relative dependence-independence among design concepts, the numerical technique of squaring the element values was used to exaggerate the presence of cell frequencies greater than one (a reasonable cutoff point since cell frequencies of zero and one were determined (above) to be nonchance occurrences) with the larger cell frequencies being increasingly emphasized. The sums of the squared cell frequencies ("designed by equivalent design concept" responses) yielded an ordinal scale describing the independence of the fourteen design concepts.

Conclusions and Interpretations

The design concepts and the frequencies of selection are shown in Table VII. Examination of Table VII reveals that roughly one-half of the design concepts listed can be considered as essentially independent, independence being defined as those items which few, if any, of the subjects selected as being related to any other design concept. The concepts found to be most independent by the above described measure are listed below in their rank order:

(1) Unit packaging;

(2) Individual packaging;

(3) Circuit-level troubleshooting;

(4) Redundancy;

(5) Manual control;

(6) Scale-type information.

If one looks at those concepts which are related to other concepts (with a frequency of 7 or 8), the following relationships appear:

(1) Automation and semi-automation are related to:

(a) self check capability;

(b) modularized equipment;

(c) module troubleshooting;

(d) go/no-go information (automation only).

(2) Manual control is related to:

(a) multi-purpose equipment;

(b) scale-type information

(3) Self-check capability is related to:

(a) modularized equipment

(4) Modularized equipment is related to

(a) module troubleshooting.

It is therefore likely that if the designer automates his equipment, wholly or partially, he will tend to provide a self-check capability, modules and go/no-go information. If he decides to design his equipment for manual operation, he is likely to develop multi-purpose equipment and present quantitative information in scale type displays.

TABLE VII

RESULTS OF TEST F

(DESIGN INDEPENDENCE TEST)

	Complete Automation	Semi-automation	Manual Control	Self-check capability	Multi-purpose equipment	Special Purpose equipment	Modularized equipment	Unit packaging	Individual packaging	Circuit-level troubleshooting	Module troubleshooting	Go/No-Go information	Scale type information	Redundancy
1. Complete automation		2	0	7	4	6	7	2	3	2	7	7	2	4
2. Semi-automation			1	7	5	4	7	3	3	2	7	6	3	4
3. Manual control				1	7	3	5	2	5	3	3	2	7	0
4. Self-check capability					4	3	7	1	2	2	6	6	2	4
5. Multi-purpose equipment						1	4	3	3	4	3	3	6	2
6. Special-purpose equipment							5	3	2	2	6	6	3	3
7. Modularized equipment								2	1	0	7	5	1	4
8. Unit packaging									2	3	2	3	0	0
9. Individual packaging										4	1	1	2	0
10. Circuit-level troubleshooting											1	0	3	0
11. Module troubleshooting												5	4	1
12. Go/No-Go information													1	3
13. Scale type information														0
14. Redundancy														

3. <u>What priority do engineers assign to design parameters (including skill and other HRD inputs) in making design tradeoffs?</u>

Test D was directed at answering this question.

TEST D

DESIGN TRADEOFF PRIORITIES TEST

<u>Test Description and Instructions</u>

In this test we wished to determine the importance of HRD inputs relative to other design parameters in any tradeoffs the engineer might make. A similar test item has been included in a number of previous studies performed by the authors and this test item would help to corroborate or disprove those previous findings. The value assigned by the engineer to various items of personnel data would help to suggest the relative weight which should be attached to these data items in SOW's or in human factors inputs provided during system development.

"Every design involves a number of tradeoffs. Some of these may be more important than others. To find out which design parameters you consider more or less important in tradeoffs, we ask you to rank the parameters listed below in decreasing order of importance. Assume you are considering two alternative designs for maintenance ground equipment. The decision to be made is to be determined by the design parameters listed below. Which of these parameters would you consider most important in terms of affecting your design decision?

1. <u>Cost</u> of developing the first prototype.

2. <u>Manpower life cycle cost</u> - the cost of training and supporting the crew which will operate and maintain the equipment from the time the equipment becomes operational to the time it is inventoried out of service.

3. <u>Equipment reliability</u> - probability that the equipment will perform its functions when required.

4. <u>Equipment performance capability</u> - the capability of the equipment to perform to mission requirements.

5. <u>Producibility</u> - ability to produce the equipment within a reasonable cost and schedule.

6. <u>Length of training</u> - length of time required to train personnel to run the equipment as required.

7. Cost of training - cost of training personnel to function as required.

8. Quantity of personnel available - number of personnel in the military inventory available to man the equipment being designed.

9. Skill availability - type of skilled personnel available to operate and maintain the equipment.

10. Maintainability - ability to keep the equipment in an "up" condition and restore it to functioning status when it has malfunctioned.

11. Development schedule - length of time needed to deliver the first prototype to the customer.

12. Personnel skill required by the equipment design - these are skills, defined in terms of the 19 parameters presented in series B (if you have forgotten these, please review their definitions).

"For example, one design might increase cost but reduce the length of time required for training personnel. Or one might improve producibility but also increase cost. You have to decide which of these parameters is most important. Rank the most important parameter 1, next most important 2, etc."

Statistical Analysis

The ranks assigned to the various design parameters are summarized in Table VIII. Kendall's W statistic (Siegel, 1956) was applied to the rankings to determine subject consistency. $W = .77$, which is significant at the .001 level, indicating that the subjects were almost unanimous in their judgments. The results of this test corroborate in every way the results of similar tests administered in earlier studies.

Conclusions and Interpretations

As one might expect, engineers place a much higher value on physical and cost parameters, which are by their very nature restrictive, than they do on personnel parameters. All the personnel items are ranked below the physical/cost parameters. It is however interesting that the most important personnel parameter to engineers is skill level required by equipment.

The fact that engineers assign a low priority to personnel inputs should come as no surprise to anyone familiar with the design process or with the preceeding studies of engineers (e.g., Meister and Farr, 1966 and Meister and Sullivan, 1967). For this reason it is important that additional emphasis be placed on timely personnel inputs in order to secure a more equal distribution of the engineer's attention.

TABLE VIII

RESULTS OF TEST D
(DESIGN TRADEOFF PRIORITIES TEST)

Item	Rank
Equipment Performance Capability	1
Equipment Reliability	2
Cost	3
Maintainability	4
Producibility	5
Development Schedule	6-7 (Tie)
Personnel Skill Required by Equipment Design	6-7 (Tie)
Skill Availability	8
Manpower Life Cycle Cost	9
Quantity of Personnel Available	10
Length of Training	11-12 (Tie)
Cost of Training	11-12 (Tie)

4. <u>How are design concepts related in the engineer's opinion to the amount of training required by these design concepts?</u>

Test I was directed toward answering this question.

TEST I

DESIGN VS. TRAINING TEST

<u>Test Description and Instructions</u>

"In Test F we gave you a set of design concepts. We want you to analyze the same set of design concepts in terms of the amount of training that would be required to enable a technician to operate and maintain an equipment designed according to these concepts. Each design concept has been typed on a separate card. Take the card deck and arrange the cards in order of the <u>amount of training</u> you feel would be required for that type of equipment. The card on top should indicate the greatest amount of training required, the second card, the next greatest amount of training, etc."

<u>Statistical Analysis</u>

The ranks assigned to these design concepts were consistent at a highly significant level ($W = .44$, $p = .001$). Table IX lists the design concepts in their ranked order.

<u>Conclusions and Interpretations</u>

It would appear that the various design concepts are significantly related to the amount of training required. It is interesting to note, in view of our earlier hypothesis that troubleshooting is a primary dimension of maintenance skill, that circuit level troubleshooting stands almost in a class by itself (mean rank of 1.6) in terms of the amount of training this design concept requires.

It would be highly desirable if one could specify in a procurement requirement that a given amount of training was to be provided to new system personnel; and to anticipate that consequently a particular design concept would be employed by the engineer. The fact that such relationships can be drawn, albeit in the very crude manner indicated by this test, suggests that some such procedure will eventually be feasible. The relationship between design concepts and training should be explored further because it offers substantial potential improvement in performance efficiency and reduction in cost.

Since design concepts are related to both skill level (Test G) and training (Test I), it is interesting to determine the extent of that co-relationship.

In Test G subjects were asked to describe the relationship between design concepts and skill level. In Test I the same design concepts were presented to engineers and they were asked to indicate the amount of training required for each design concept.

The frequencies across the three categories in Test G were each weighted with respect to skill level and summed. A ranking based on skill level was then assigned to each design concept on the basis of the sum. These ranks were then correlated with the ranks assigned in Test I, using the Spearman rank-order correlation technique (Siegel, 1956). The results indicate a highly significant level of agreement ($r_s = .91$, $p = .01$). The extent of the agreement appears to be a function particularly of those items classed as requiring skilled maintenance personnel. In those items of Test G where the subjects indicated that it made "no difference" as to the skill level of personnel, there was a much lower consistency in subject responses.

TABLE IX

RESULTS OF TEST I

(DESIGN VS. TRAINING TEST)

Items	Mean Rank	Relative Rank	Amount of Training Req'd.
Circuit Level Troubleshooting	1.6	1	Most
Multi-Purpose Equipment	4.1	2	
Scale Type Displays	5.4	3	
Individual Packaging	5.7	4	
Unit Packaging	5.9	5	
Manual Control	6.0	6	
Redundancy	7.5	7	
Semi-Automatic	8.8	8.5	
Module Troubleshooting	8.8		
Complete Automation	9.6	10	
Modularized Equipment	9.7	11	
Self-Check Capability	10.3	12	
Special Purpose Equipment	10.4	13	
Go/No-Go Information	11.0	14	Least

5. <u>What skill dimensions are considered by engineers to differentiate different levels of maintenance technician skill?</u>

Three tests, A, B and H, were directed toward answering this question. Each is discussed separately.

TEST A

SKILL DIMENSIONS TEST

<u>Test Description and Instructions</u>

"The following is a set of cards on each of which there is a statement which describes how maintenance technicians perform. Read each statement carefully and put <u>S</u> in front of the statement if you believe it is more characteristic of a <u>skilled</u> maintenance man. Put <u>U</u> in front of the statement if you believe it is more characteristic of an <u>unskilled</u> or <u>less skilled</u> man. If you lack sufficient information to make a judgement, or you feel the description is unrelated to skill, put a question mark beside the item. You must categorize each statement; do not miss any."

(Shuffle cards for each subject. Give cards to subject individually.)

There are nineteen parameters and two descriptors for each parameter (hence thirty-eight items). A descriptor is an incident which describes the parameter in actual performance. One descriptor illustrates the behavior of the skilled technician; the other illustrates the behavior of the unskilled technician.

Each parameter is listed in Table X above the two descriptors which represent that parameter. (Subjects did not, of course, see the parameter categories, which are presented here only for the reader's benefit.) One descriptor describes the parameter as one sees it in the skilled man; the other descriptor describes the parameter in the unskilled man. The descriptors are listed in Table X together with the chi-square (X^2) value indicating degree of agreement among subjects on that descriptor.

<u>Statistical Analysis</u>

Table X indicates that for approximately half of the descriptive statements the subjects agreed at a highly significant level (.01 or better) that these kinds of behavior are capable of distinguishing between skilled and unskilled personnel. The test used to determine the degree of agreement among subjects was the X^2 one-sample test (Siegel, 1956).

TABLE X

RESULTS OF TEST A

(SKILL DIMENSIONS TEST)

	S	U	?	X^2	P
***Integration of Information**					
1. Prefers to have his maintenance information displayed on quantitative meters or indicators so he can analyze their meaning for diagnostic purposes.	7		1	10.75	.01
2. Prefers go/no-go indicators because the equipment information is already integrated and analyzed.		4	4	4.0	NS
***Speed**					
3. Performs maintenance procedures very quickly, without being careless.	7		1	10.75	.01
4. Works slowly and cautiously. Often repeats steps in the procedure.		4	4	4.0	NS
***Responsibility**					
5. This technician is the only one allowed to troubleshoot the system all by himself.	7		1	10.75	.01
6. Usually asks another technician to check his work before signing the job off.	1	4	3	1.75	NS
***Work Aids**					
7. Rarely uses a written procedure to run through a programmed checkout. In troubleshooting the system, he rarely uses a manual or schematics unless the malfunction is difficult to isolate.	7		1	10.75	.01
8. Always uses a checklist or other instructions in performing all but the most routine maintenance jobs.	2	2	4	1.0	NS

*Skill Parameters

TABLE X (Cont'd.)

	S	U	?	X^2	P
***Accuracy**					
9. Almost never makes errors in performing status checks of the ground control systems.	4		4	4.0	NS
10. Tends to make errors in his checkouts and, when the equipment will not check out, has difficulty finding his error.		8		16.0	.001
***Supervision**					
11. The others on the crew prefer to have this technician check their work out or at least to be around to help in case they run into a problem.	7		1	10.75	.01
12. Is almost never asked to help when another crew member has difficulty.		4	4	4.0	NS
***Knowledge**					
13. Understands the electronic theory underlying the functioning of the systems he maintains and can explain the reasons for malfunction symptoms.	8			16.0	.001
14. Goes through his maintenance procedures by rote and often has difficulty understanding why a particular trouble symptom has occurred.		8		16.0	.001
***Experience**					
15. Has been working as a maintenance technician on this and other electronic systems for the past 5 years.	5		3	4.75	.10
16. Has worked as a maintenance man for 6 months.		4	4	4.0	NS

*Skill Parameters

TABLE X (Cont'd.)

	S	U	?	X^2	P
***Training**					
17. In addition to basic maintenance training on the system, this technician attended an advanced school for troubleshooting the system and a special four-week postgraduate course at the factory.	7		1	10.75	.01
18. Has had basic electronics training only.	1	6	1	6.25	.05
***Motor Coordination**					
19. This technician is extremely clever with his hands. His wiring hook-ups are extremely neat, and he is called on whenever a very tricky equipment calibration must be performed.	7		1	10.75	.01
20. This technician is "all thumbs"; his wiring hook-ups are sloppy, and he is slow in removing and replacing components.	1	6	1	6.25	.05
***Problem Solving**					
21. This technician seems to have the knack of troubleshooting the system. Whenever a difficult malfunction isolation problem arises, he seems to be able to solve it.	8			16.0	.001
22. This technician generally leaves troubleshooting to his buddy, because he has difficulty in isolating even fairly common malfunctions.		8		16.0	.001
***Self-Confidence**					
23. Problems do not faze this technician, and he actually volunteers to perform complex maintenance jobs like troubleshooting.	7		1	10.75	.01

*Skill Parameters

TABLE X (Cont'd.)

	S	U	?	X^2	P
***Self-Confidence (Cont'd.)**					
24. This man is often hesitant about the procedures he should follow and will repeat a step several times to make sure it is correct; or he will call another technician to check his work.		6	2	7.0	.05
***Use of Instruments**					
25. Is familiar with and has used a wide variety of test equipment like oscilloscopes, circuit board testers, and calibration equipment.	4		4	4.0	NS
26. Is unfamiliar with the less common items of test equipment and has used them infrequently.		6	2	7.0	.05
***Innovation**					
27. Likes to try novel approaches to the solution of difficult maintenance problems. He often improves tools or improvises special "lash-ups".	7		1	10.75	.01
28. This technician follows troubleshooting procedures rigidly, taking no short cuts and making no guesses.	3	2	3	.25	NS
***Rank**					
29. Holds a 7-level (Crew Chief) position in the Air Force.	6		2	7.0	.05
30. Is a 3-level (Apprentice) technician in the Air Force.	1	6	1	6.25	.05

*Skill Parameters

TABLE X (Cont'd.)

	S	U	?	X^2	P
***Intelligence**					
31. When a new piece of equipment is introduced, this technician is among the first to learn now to maintain it.	7		1	10.75	.01
32. This technician is usually the last man on the crew to learn maintenance procedures for a new piece of equipment.		4	4	4.0	NS
***Flexibility**					
33. This technician can perform just about every maintenance job required by the system, switching from one to the other easily.	8			16.0	.001
34. This man has specialized in one or two maintenance jobs.	3	4	1	1.75	NS
***Stress Performance**					
35. Even when deadlines are tight, this technician is unflustered and performs just about as well as he usually does.	3		5	4.75	.10
36. When deadlines are tight, this man tends to become upset and works harder to meet the deadline.		1	7	10.75	.01
***Visual Capacity**					
37. This technician seems to be able to see at a glance when a component or circuit has something wrong with it.	7		1	10.75	.01
38. This man often fails to notice when something is wrong with a component.		7	1	10.75	.01

*Skill Parameters

Conclusions and Interpretations

Table X indicates that the parameters which enter into the determination of skill are a function of which significance level or amount of agreement one wishes to accept. The .001 level means that all eight subjects agreed on the classification of a descriptor; the .01 level means that seven agreed and one disagreed. Accepting those descriptors which are significant at the .01 level we find that: knowledge, troubleshooting ability, flexibility, responsibility, speed, work aids, supervision, motor coordination, self-confidence, innovation, intelligence, and visual capacity are characteristics of a skilled technician; while lack of accuracy, lack of understanding, and inability to troubleshoot describe the unskilled man.

Detailed examination of the items on which all subjects agreed reveals a tantalizing common element. Almost all of these descriptors contained a reference, explicit or implicit, to troubleshooting. This suggests that the common factor underlying the various ways in which skill or lack of skill manifest themselves in the maintenance environment is ability to troubleshoot. As of now this suggestion can be hypothetical only, because specific questions to test this point were not developed. It is interesting, however, that Table XII(b) indicates that problem solving is ranked number 2 in terms of the components that enter into maintenance skill, with number 1 being intelligence.

In analyzing the results of this test, it becomes apparent that those behaviors described by engineers as being characteristic of skilled personnel are agreed upon with much more consistency (higher level of significance) than the remaining items. Examination of the eleven items having the lowest level of agreement among subjects reveals that nine of these items are descriptions of unskilled performance. It is possible that engineers have the ability to recognize what is obviously skilled behavior, but are unable to agree as to what constitutes unskilled behavior.

TEST B

SKILL IMPORTANCE TEST

Test Description and Instructions

This test represents another way of probing skill dimensions. In

Test A (Skill Dimensions), only the descriptive incidents were presented, without any parameter title which might have served to organize the concept for the subject. In Test B the parameter title was presented and defined. In addition, the subject indicated the contribution of the individual parameter to skilled maintenance performance on a 5 point scale.

While it is impossible to directly correlate the results of Tests A and B, one would expect to find the most important parameters of test A making the greatest contribution to maintenance skill. Because of the manner in which the test question was asked, one would also expect that even parameters on which there was no significant agreement in Test A would show up as having some effect on skill.

"The items below are descriptions of the various ways in which maintenance men may differ in terms of their skill level. We want to find out which characteristics are more important in terms of the way you define skill. For ease of presentation we summarized each skill parameter in a short phrase, like accuracy, knowledge or motor coordination. In the list below the parameters are defined. After you have studied these definitions carefully, we will ask you to rank each skill description with regard to its importance in maintenance skill.

"The scale runs from 1 to 5 with 1 being of little importance and 5 representing a highly critical component of maintenance skill. We ask that you make a check at the level of importance that you think represents the importance of that skill factor in maintenance performance."

LIST OF PARAMETER DEFINITIONS

1. Integration of Information

The highly skilled maintenance man is able to integrate information from different quantitative displays (e.g., meters) and to interpret its meaning. The less skilled maintenance man is less able to do this.

Minor Importance In Maintenance Performance	1	2	3	4	5	Critical To Maintenance Performance

(Scale was repeated for all subsequent items.)

2. Speed

The highly skilled maintenance man performs maintenance checkouts rapidly; the less skilled man is slower and may repeat steps.

3. Responsibility

The highly skilled man performs his maintenance tasks by himself, without asking assistance of others or needing others to monitor him.

4. Work Aids

The highly skilled man usually performs his tasks without the aid of checklists, tech manuals or written instructions; the less skilled man always uses checklists or other instructions in performing his task.

5. Accuracy

The skilled man makes relatively few errors that require him to repeat his work; the unskilled man makes many more errors and tends to repeat his work.

6. Supervision

The skilled man either supervises others or is referred to by others for assistance or approval of work performed. The less skilled man does not supervise or assist others, although he may be able to do his own work satisfactorily.

7. Knowledge

The skilled man has considerable general knowledge (electronic theory, maintenance techniques) as well as specific information about his equipment.

8. Experience

The skilled man has worked as a maintenance technician on this and similar systems for a number of years; the unskilled man has much fewer years of experience.

9. Training

The skilled man has been given extensive schooling (for example, advanced schools and factory training) in his maintenance specialty; the less skilled man has received much less formal training.

10. Motor Coordination

The skilled man has very fine manual dexterity and is capable of precise wiring, calibration and removing and replacing components quickly; the unskilled man is much slower and less precise in his movements.

11. Problem Solving

The highly skilled maintenance man is capable of solving complex, nonroutine maintenance problems such as are found in troubleshooting; he can interpret the meaning of trouble symptoms; the less skilled man has difficulty solving these problems.

12. Self Confidence

The highly skilled maintenance man has no hesitation about volunteering to perform more complex maintenance jobs; he "seems to know what he is doing." The less skilled man appears to hesitate when starting a job, as if he were not quite sure of the next step.

13. Use of Instruments

The highly skilled maintenance man has used a wider variety of test equipment (like oscilloscopes), and is familiar with their operations. The unskilled man is much less familiar with and has used these instruments much less.

14. Innovation

The skilled man may try novel approaches to the solution of a problem, such as procedural short cuts. The unskilled man follows standard maintenance procedures rigidly.

15. Rank

The skilled man has higher Air Force rank than the unskilled.

16. Intelligence

The skilled man learns new maintenance procedures quickly and easily; he can readily relate what he has learned to new equipment. The less skilled man learns more slowly and has difficulty applying what he has learned in the practical situation.

17. Flexibility

The skilled man can perform a wide range of maintenance jobs and switches quickly and easily from one type of job to another. The less skilled man has difficulty in doing so.

TABLE XI

RESULTS OF TEST B

(SKILL IMPORTANCE TEST)

Item	Scale Value *	Rank	X^2	P
Integration of Information	4.5	1.5	10.8	.05
Knowledge	4.5		10.8	.05
Accuracy	4.3	3.5	13.25	.02
Problem Solving	4.3		10.8	.05
Training	4.1	6.5	10.8	.05
Use of Instruments	4.1		23.25	.001
Flexibility	4.1		10.8	.05
Stress Performance	4.1		5.75	NS
Visual Capacity	4.0	9.5	4.5	NS
Responsibility	4.0		10.8	.05
Intelligence	3.7	11	3.25	NS
Self-Confidence	3.5	12	9.5	.05
Innovation	3.3	13	13.25	.02
Supervision	3.1	14	10.8	.05
Motor Coordination	3.0	16	5.75	NS
Speed	3.0		5.75	NS
Experience	3.0		5.75	NS
Rank	2.6	18	2.0	NS
Work Aids	2.3	19	15.75	.01

* Represents mean scale value

18. Stress Performance

When required to work more quickly to meet a shortened deadline, the skilled man does so without loss of efficiency; the less skilled man starts to make errors and has to repeat himself.

19. Visual Capacity

The skilled man appears to have keener visual perception than the less skilled man; he is quicker in locating components and seeing what is wrong with them than the less skilled man.

Conclusions and Interpretations

In twelve of the nineteen items ranked by the subjects there was significant level of agreement (.05 or better) as to the value of that item as a contributing factor to maintenance skill.

Table XI indicates that of the four highest ranked parameters in Test B, three (knowledge, accuracy and problem solving) were the same ones considered in Test A to differentiate most accurately between skilled and unskilled performance. The fourth parameter found to be important in Test A (flexibility) ranks immediately below problem solving in Test B. Hence the results of Test B tend to confirm the results of Test A.

TEST H

SKILL RANKING TEST

Test Description and Instructions

"The items below are descriptions of the various ways in which maintenance men may differ in terms of other skill level. Some of these ways may be more important than others in determining overall maintenance skill. After you study the list of definitions you will be given a deck of cards on each of which one definition has been typed. Please sort the deck of cards so that the most important factor is on top, the next most important is second, and so forth until all nineteen cards have been ordered. Do not leave out any of the nineteen cards. If you feel that any of these factors is unimportant in determining maintenance skill, make a note of that factor and tell me afterwards."

Conclusions and Interpretations

The nineteen parameters presented in this test were those of Test B (Skill Importance). If the results of Test B are compared (Table XII (b)) with the results of ranking in Test H (which is the same question

asked in a different manner), we find that there is an extremely high correlation between the two rankings ($r_s = .71$, $p = .01$). Essentially what is represented here, in a hierarchical order of importance, is the design engineer's concept of what constitutes the skill of the personnel for which he is designing equipment.

The several reversals in rank value between the parameters ranked in Test B and those ranked in Test H are explainable, perhaps, in terms of the fact that Test B is asking what the contribution (in an absolute sense) of a particular parameter is to maintenance performance, whereas Test H inquires into the value of the parameter relative to all the other parameters influencing maintenance performance. Nevertheless, parameters ranked 2, 3, 4 and 5 in Test H are the same parameters ranked highest in Test B.

Table XII(a) indicates the ranks assigned in this test. Kendall's W (Siegel, 1956) statistic was applied to determine the consistency of subjects' rankings. The W value derived ($W = .43$, $p = .001$) indicates an extremely significant level of agreement among subjects relative to skill parameters.

Discussion of Conclusions Relative to Question 5

The fact that agreement can be reached among engineers on the parameters entering into maintenance skill is highly encouraging and should be followed further.

Additional investigation should be made of the hypothesis that troubleshooting ability is a generalized factor influencing the engineer's concept of maintenance skill level. It may be possible to differentiate various aspects of troubleshooting and thus secure a more precise definition of maintenance skill.

In any event it would appear feasible to prepare personnel skill requirements for new system development in terms of the more highly ranked skill parameters. Phrased in this way, such skill requirements may be more meaningful to engineers than the presently employed Air Force Specialty Code, 3, 5, 7 level designations.

TABLE XII (A)

RESULTS OF TEST H

(SKILL RANKING TEST)

Item	Rank
Intelligence	1
Problem Solving	2
Accuracy	3
Knowledge	4
Integration of Information	5
Flexibility	6
Self-Confidence	7
Responsibility	8
Supervision	9
Training	10
Use of Instruments	11
Experience	12.5
Stress Performance	12.5
Speed	14.5
Motor Coordination	14.5
Innovation	16
Visual Capacity	17
Work Aids	18
Rank	19

TABLE XII (B)

RESULTS OF TEST B (SKILL IMPORTANCE)

COMPARED WITH TEST H (SKILL RANKING)

Item	RANK Test B	RANK Test H
Integration of Information	1.5	5
Knowledge		4
Accuracy	3.5	3
Problem Solving		2
Training	6.5	10
Use of Instruments		11
Flexibility		6
Stress Performance		12.5
Visual Capacity	9.5	17
Responsibility		8
Intelligence	11	1
Self-Confidence	12	7
Innovation	13	16
Supervision	14	9
Motor Coordination	16	14.5
Speed		14.5
Experience		12.5
Rank	18	19
Work Aids	19	18

6. How many levels of skill can be differentiated by engineers?

Test J was directed at answering this question.

TEST J

SKILL LEVEL DIFFERENCES TEST

Test Description and Instructions

"The following items describe different levels of maintenance skill. On the scale below, which runs from completely unskilled to completely skilled, write the number of the skill level item where you think that level of skill belongs. Note that the skill levels described are not necessarily equally spaced along the scale and you do not have to, unless you want to, space them equally."

Skill Levels

1. Supervises trainees in performance of simple maintenance tasks.
2. Performs all maintenance tasks, including complex troubleshooting, without supervision.
3. Basic schooling; no experience at all.
4. Responsible for performance of entire maintenance crew.
5. Allowed to perform simple maintenance routine on his own.
6. Learner; acts only as assistant to more experienced technicians.
7. Allowed to perform simple, routine checkouts under supervision.
8. Performs complex maintenance tasks under supervision.
9. Supervises less skilled men in troubleshooting tasks.
10. Able to troubleshoot to the circuit level.

Completely Unskilled	Completely Skilled

Conclusions and Interpretation

Table XIII contains the ranks assigned to each of the items. Using Kendall's "W" statistic (Siegel, 1956), agreement between our subjects on this item was extremely significant ($W = .8$, $p = .001$).

Discussion

From the results of Table XIII it would appear that engineers can differentiate a number of levels of maintenance skill. Although there is some

overlapping in subject rankings, if one were to plot their distribution in graphic form, it would approximate a straight line. This suggests that the points on the skill continuum described by the various skill levels in Table XI represent valid stages in skill progression.

Earlier studies indicated that engineers had great difficulty in understanding differences among the Air Force's 3, 5, 7-levels. One can conclude from this test that engineers are capable of differentiating a larger number of skill levels when these are phrased in performance terms than if they are phrased in terms of artificial categories. It may therefore be useful in specifying manpower requirements in procurement documents to describe skill levels in terms of performance as well as the Air Force's AFSC designations.

TABLE XIII

RESULTS OF TEST J
(SKILL LEVEL DIFFERENCES TEST)

DISTR'BUTION OF JUDGMENTS

Skill Levels	1	2	3	4	5	6	7	8	9	10	Mean Rank	Relative Rank	
													Least
Basic schooling; no experience at all	5 1	2									1.3	1	Skilled
Learner acts only as assistant to more experienced technicians	2 1	5									1.7	2	
Allowed to perform simple, routine checkouts under supervision			7 1								3.1	3	
Allowed to perform simple maintenance routine on his own			1	6	1						4.1	4	
Performs complex maintenance tasks under supervision					3	3 1	1				5.8	5	
Able to troubleshoot to the circuit level					3	2	1	1 1			6.3	6	
Supervises trainees in performance of simple maintenance tasks					3	1	1 2		1		6.5	7	
Supervises less skilled man in troubleshooting tasks						1	1 1	3 1	1		7.8	8	
Performs all maintenance tasks, including complex troubleshooting without supervision								1	5 2		9.0	9	
													Most
Responsible for performance of entire maintenance area							1	1	1 1	4	9.3	10	Skilled

7. <u>What is the relationship in the engineer's mind between skill level and years of experience?</u>

Test E-1 was directed toward answering this question.

TEST E-1

SKILL VS. EXPERIENCE LEVEL TEST

Test Description and Instructions

Test E-1 was designed to investigate the degree to which engineers equate experience (time) on the job with skill. It was hoped that it might be possible to derive some skill/experiential standards based upon the engineers view of the time/experience continuum.

"Assuming that the technician's skill is related in some way to the amount of experience he has, and without considering the type of experience, please indicate on the following scale whether a technician with certain years of experience is

1. Unskilled
2. Slightly skilled
3. Moderately skilled
4. Highly skilled

Graduation from basic electronics school	6 mos. exp.	1 yr. exp.	18 mos. exp.	2 yrs. exp.	$2\frac{1}{2}$ yrs. exp.	3 yrs. exp.	$3\frac{1}{2}$ yrs. exp.	4 yrs. exp.	$4\frac{1}{2}$ yrs. exp.	5 yrs. exp.	10 yrs. exp.

(Please bracket () on the scale the four levels of skill which a technician would have based on experience alone, all other things being equal.)"

Statistical Analysis

Only seven subjects responded to the question. Subject number eight refused to consider the possibility that length of time on the job was by itself in any way related to skill.

The responses of our seven subjects produced the following averages and ranges for the four categories of skill:

TABLE XIV

RESULTS OF TEST E-1
(Skill vs. Experience Level Test)

Item	Average	Range
1. Unskilled	6.1 mos.	1 mo. - 12 mos.
2. Slightly Skilled	17.0 mos.	3 mos. - 30 mos.
3. Moderately Skilled	36.3 mos.	6 mos. - 60 mos.
4. Highly Skilled	36.3 mos.	

Conclusions and Interpretations

Since the range of responses is so great, it is apparent merely from inspection that consistency is insignificant and further statistical treatment is not warranted. Apparently the engineer does not consider time on the job by itself as a significant descriptor of skill.

C. CONCLUSIONS

1. Design characteristics significantly related to low skill level appear to be: test points; internal components; checkout procedures; type of test equipment required; go/no-go displays; troubleshooting and step by step procedures.

2. The following design concepts are considered by the engineer to be relatively independent entities: unit packaging; individual packaging; circuit level troubleshooting; redundancy; manual control and scale type information.

3. Design concepts and characteristics are related in the engineer's mind to different skill levels. Given a particular skill requirement, the engineer is more likely than not to include in his design characteristics that he considers appropriate to that skill requirement.

4. The engineer conceptualizes maintenance skill in terms of knowledge, troubleshooting ability and flexibility; lack of skill is described by lack of accuracy, failure to understand and inability to troubleshoot. A common denominator of skill parameters appears to be troubleshooting ability.

5. The engineer has a concept of skill level which is more operationally and performance-oriented than described by the Air Force Specialty Code designations.

6. The individual design concepts are significantly related in the engineer's mind to the amount of training required. A specification of the amount of training to be given to system personnel will therefore influence the type of design concept incorporated into new equipment.

7. Skill level appears not to be related in the engineer's mind to years of experience.

SECTION IV

RECOMMENDATIONS

In order to influence system design, engineers must be provided with personnel requirements which are meaningful to them in terms of design implications. Manpower requirements usually incorporated in procurement documents do not satisfy this criterion. The reason for this is the serious lack of data on personnel-design relationships. The present study has made a very tentative stab at uncovering these relationships and it is encouraging to note that under controlled conditions (as in this study) engineers appear to recognize the validity of these relationships. Much more, however, remains to be done. Later in this section recommendations for further research will be presented; for the moment the immediate implications of the study should be considered.

As a result of the present study and others performed (eg, Meister et al., 1968 and 1969), it is apparent that engineers will disregard manpower requirements phrased in general terms such as, "design to minimize skill level". It is therefore necessary for the human resources specialist to include in procurement documents highly explicit requirements which have the following characteristics:

(1) Manpower requirements should be phrased as explicit design requirements.

(2) Indicate the maximum number of personnel allowed for operation and maintenance of the system.

(3) Indicate the distribution of skill level of these personnel.

(4) Indicate the amount of training which will be given these personnel and the level of proficiency they can be expected to attain.

(5) Skill level should be phrased in performance terms (ie, in terms of what the personnel can be expected to do while operating and maintaining the system).

(6) The design implications of manpower requirements should be explicitly stated as desired outputs of system design (eg, personnel should (or should not) be expected to troubleshoot at the circuit level).

The inclusion of such manpower requirements in procurement documents will not necessarily cause the engineer to give these requirements the highest priority in his design, but they will cause him to think more seriously of his design in terms of personnel implications.

The study also suggests certain fruitful areas for further work. The nature of equipment design makes particular demands upon personnel in terms of the skills needed to operate and maintain that equipment. From that standpoint it is necessary to analyze the various equipment designs available or projected to become operational in the Air Force to determine the tasks they impose on personnel and the skills they will require. As new equipment enters the inventory, new skills may well be required; studies of present equipment may suggest the new skills which may be demanded. In any event, skill as a dimension of personnel performance cannot be studied apart from the operational context in which that skill must be utilized.

Since the essence of the problem seems to be to relate manning and skill level to concrete design concepts and characteristics, it is suggested that this area have high priority in further explorations. The present study has suggested certain relationships, but these deal only with a particular type of maintenance equipment. It is recommended that an an analysis be made of different types of operator and maintenance systems and that the manning and skill dimensions pertinent to the design characteristics of these systems be uncovered.

Such a study could be performed by

(1) Developing a taxonomy of design concepts and characteristics which differentiate various types of operator/maintenance systems, eg, airborne, ground, command/control, maintenance, etc.

(2) Selecting various operational systems in the Air Force inventory which are representative of the various classes of design concepts and characteristics within the taxonomy of (1) above.

(3) Going to the air bases at which these systems are to be found and performing an analysis of the various task behaviors required by the different design concepts/characteristics.

(4) Determining from the operators/maintenance technicians who utilize the equipments the various manning/skill parameters involved in these behaviors. The design-skill relationships uncovered in the present study would be investigated in operational performance and correlated with the results of the present study. This might require the development of and administration to operational personnel of tests to uncover the manning/skill parameters which differentiate effective from non-effective performance on particular types of equipment. Additional data would be gathered relative to:

   (a) the type of training provided to personnel of the various systems.

   (b) the kinds of personnel performance problems experienced in operating and maintaining these systems.

(5) The end product of this study would be the development of what can be termed a "human resources data system development handbook", consisting of descriptions of the various classes of equipment and their design characteristics, together with the manning/skill dimensions required to operate and maintain that equipment, applicable training data, characteristic task behaviors, etc.

Such a handbook could then be provided to Air Force managers and design engineers, so that, given a requirement to develop a system of a given type, they could look up the appropriate equipment design type, and find the manning dimensions required for that equipment. Such a handbook could be updated periodically as new types of equipment (e.g., micro-electronic circuitry) enter the inventory. Appropriate parts of the handbook could be referred to in procurement specifications for new equipment as a guide to the manager and engineer.

What has been described is not simply another form of job analysis, although it contains elements of such an analysis, but a highly design-oriented catalogue which could be gradually extended to cover the totality of equipment types used by the Air Force. Since the Air Force expects engineers to consider manning requirements in their design, it would seem only reasonable to supply the engineers with the appropriate information they need to consider these requirements.

The utility of such a handbook could be tested by utilizing the same research strategy employed in the present study, that is, by giving a sample of engineers the catalogue to use in the course of performing a simulated design. Such tests would serve as feedback to enable the Air Force to supply the kind of data best suited to engineering needs for new system development.

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13. ABSTRACT

The purpose of this study was to investigate the relationships between design characteristics and skill dimensions. A series of paper and pencil tests to examine these relationships was administered to eight design engineers during two four-hour sessions. Design characteristics significantly related to skill level are test points, internal components, checkout and troubleshooting procedures, type of test equipment required and go/no-go displays. Individual design concepts are also significantly related to the amount of training required. The engineer conceptualizes maintenance skill in terms of knowledge, troubleshooting ability and flexibility. The engineer's concept of skill level is more performance-oriented than that described by Air Force Specialty Code designations. Skill level appears not to be related in the engineer's mind to years of experience.

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